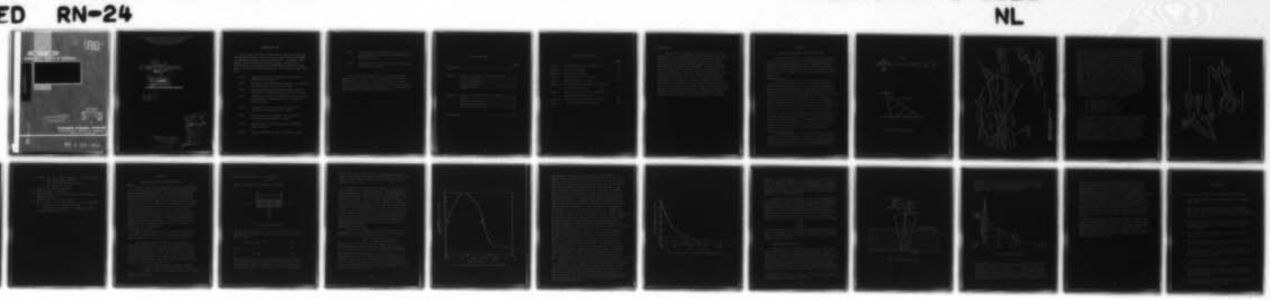
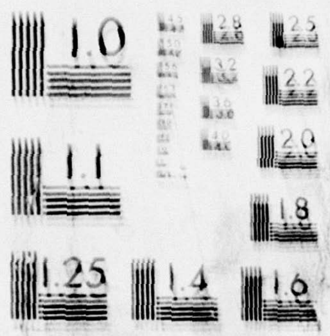
AD-A082 144 MASSACHUSETTS INST OF TECH CAMBRIDGE EXPERIMENTAL AS--ETC F/G 8/10
AN INVESTIGATION OF SIDE-LOOKING RADAR AND LASER FATHOMETERS AS--ETC(U)
OCT 67 J H ARABIAN N62306-67-C-0122
UNCLASSIFIED RN-24 NL

1 OF 1
AD
A082144



END
DATE
FILMED
4-80
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

EXPERIMENTAL ASTRONOMY LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE 39, MASSACHUSETTS

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS
EXPERIMENTAL ASTRONOMY LABORATORY
CAMBRIDGE, MASSACHUSETTS 02139

14 RN-24

6 AN INVESTIGATION OF SIDE-LOOKING RADAR AND LASER FATHOMETERS AS HYSURCH SENSORS

by

10 J. H. Arabian

11 Octo[redacted]67

Contract 15 N62306-67-C-0122

12 26

EXPLANATORY NOTE

This is one of a series of Engineering Reports that document the back-ground studies to be used in a system design for HYSURCH (Hydrographic Surveying and Charting System). In general, these reports cover more detail than that finally necessary for a system design, Any subsystem recommendations contained in these reports are to be considered tentative. The reports in this series are.:

RN-22	Soundboat Navigation Equipment and Strategy for HYSURCH by John Hovorka
RN-23	The Role of the HYSURCH Survey Ship in the Production of Nautical Charts by Edwin A. Olsson
RN-24	An Investigation of Side-Looking Radar and Laser Fathometers as HYSURCH Sensors by Jack H. Arabian
RN-25	A Computation Center for Compilation, Revision and Presentation of Hydrographic Chart Materials by Edwin A. Olsson
RN-27	Parameters for the Evaluation of Sonar Depth Measurement Systems by Joel B. Searcy
RN-28	Tidal Measurement, Analysis, and Prediction by J. Thomas Egan and Harold L. Jones
RN-29	Applications of Aerial Photography for HYSURCH by A.C. Conrod
RN-30	Sounding Equipment Studies, by Leonard S. Wilk

RN-31 Error Analysis of a Dual-Range Navigation Fix and Determination of an Optimal Survey Pattern by Greg Zacharias

RN-32 Tethered Balloons for Sounding Craft Navigation Aids by Lou C. Lothrop

These reports were prepared under DSR Contract 70320, sponsored by the U.S. Naval Oceanographic Office Contract Number N62306-67-C-0122. The reports are meant to fulfill the reporting requirement on Sub-system selection as specified in the MIT proposal submitted in response to the Oceanographic Office Request for Quotation, N62306-67-R-005.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Introduction

The Sensors Investigation which this report covers is in two sections: (1) Side-Looking Radar (SLR) and (2) Laser Fathometer. As applied to the Naval Oceanographic Office Program code named Hysurch (Hydrographic Survey and Charting), Side-Looking Radar was studied for possible use in coastline delineation and landmark identification. It should be pointed out that this phase of study was for background material and does not necessarily result in a recommendation of SLR as part of the Hysurch System. The cost of SLR and the need for a relatively large fixed-wing aircraft are factors which must be weighed in the decision. The Laser Fathometer study has been temporarily separated out of the standard Hysurch schedule in order to accelerate the testing program and demonstrate feasibility for charting shallow waters. Thus, the technical specifications have already been written and submitted to the US Naval Oceanographic Office to expedite this phase of Hysurch.

SECTION 1

Sensors Investigation, Side Looking Radar

Side Looking Radar (SLR) is a consideration in Hysurch for the delineation of shoreline, topographic information along the coast, and landmark identification. Complementary possibilities include geological structure identification, ocean wave motion analysis, obstacles protruding from the water surface, ice patrol, and population movement (of vehicles or other structures).

GENERAL DESCRIPTION

The basic difference between SLR and other radars is the antenna and propagation pattern. Instead of pointing in the direction of aircraft movement, the beam is directed perpendicular to heading by means of a long fixed antenna mounted under and along the aircraft fuselage (see Fig. 1). Due to its length, it generates a narrow beam (0.1^{o} to several degrees) in azimuth, and a relatively wide (45^{o}) beam in elevation; and its mounting minimizes aerodynamic drag on the airframe. Thus, as the antenna is continually repositioned translationally along the flight path, each RF pulse of radar energy sweeps out a new line in azimuth and range, much the same way as a TV screen. An image of the terrain can therefore be swept out by the forward movement of the aircraft, and recorded on the face of a CRT, and/or on film (see Fig. 2). The separation of the targets in line with the beam is accomplished by the time difference measurement (range)of the transmitted pulse from the antenna to the target and back. The resulting record on film becomes a continuous strip map of the earth's surface.

IMAGERY AND POLARIZATION

The imagery output of SLR provides a pattern of return signals in the radar frequency range similar to, but not identical with, aerial photography. Whereas the latter operates in the optical spectrum with lenses and cameras and depends on natural daylight illumination, the former provides its own

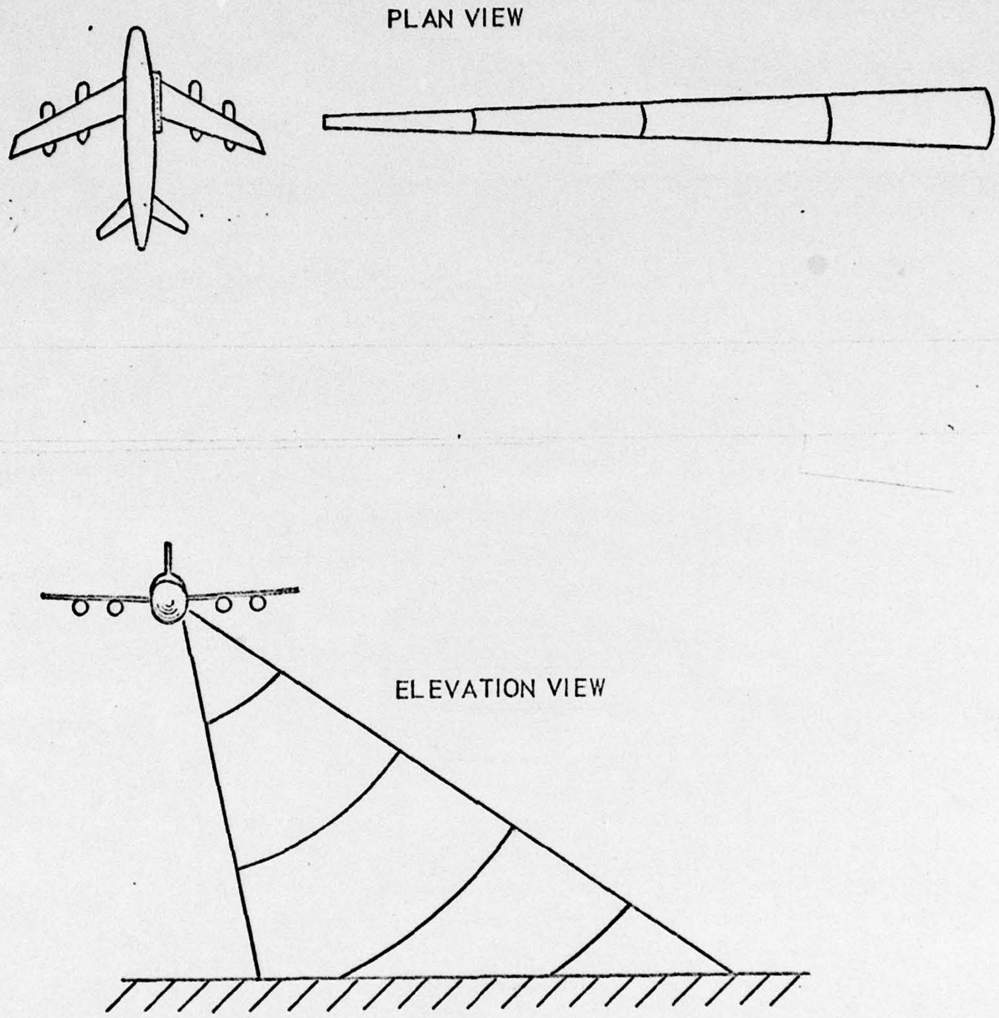


Fig. 1. SLR configuration and propagation.

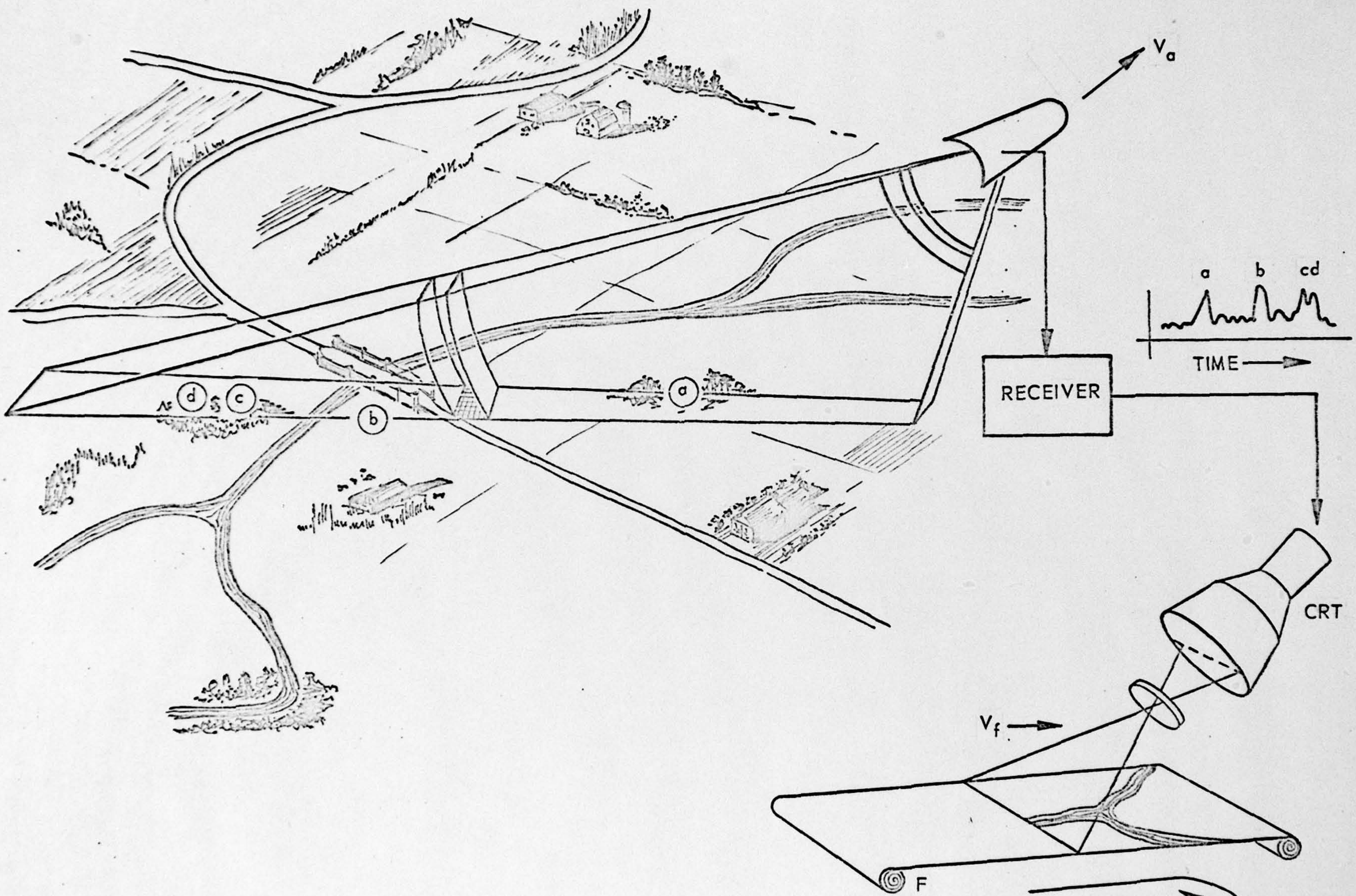


Fig. 2. SLR terrain imagery.

frequency in the K,X,C, or P bands with constant or controllable illumination. Furthermore, SLR has the advantage of being an almost all weather device (except for heavy rain), operable around the clock, and capable of sweeping wide swaths of area: 10-15 miles wide and as long a flight path as the supporting aircraft will maintain. With such a large coverage, the mosaiking problem is greatly simplified; and other more macroscopic topological features are revealed. With special techniques such as polarization, certain targets and image boundaries become more clearly or uniquely defined than with photography or non-polarized signals. If, for example, a horizontally polarized wave is transmitted, and both horozontally and vertically polarized signals are received, both images display certain terrain boundary characteristics which may otherwise be missed (see Fig. 3). The nature of the radar and its target determines the polarization of the return signal; such characteristics as the following are influential:

(a) Surface roughness of target
(b) Geometry of the target
(c) Incidence angle of radar beam
(d) Carrier frequency of radar
(e) Terrain dielectric properties.

Once the horizontally (H) polarized signal is transmitted and the horizontal (HH) "like", and vertical (HV) "cross" polarized signals are returned, the above factors and the large area of coverage combine to add more detail for the trained observer (see Fig. 4). The converse of the polarization; i.e., transmitter of V signals and receiver of VV and VH, has also been tried; and preliminary results indicate that this mode presents more power return on the sea than on land. The opposite seems to be true with a transmitter of H signals.

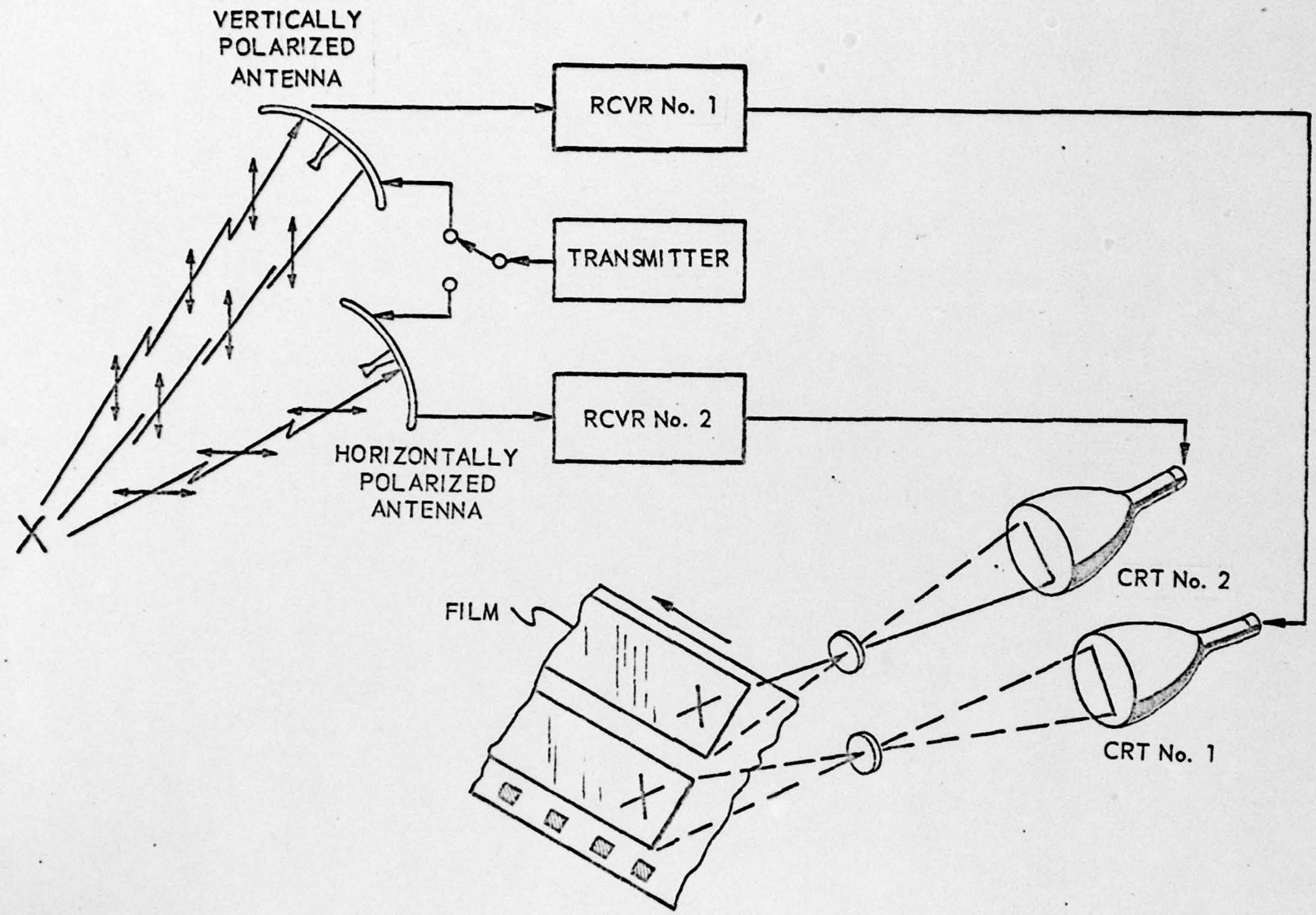
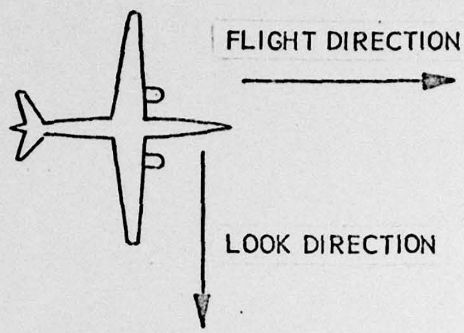


Fig. 3. SLR beam polarization.



POLARIZATION: THE SIDE LOOK RADAR SYSTEM HAS THE CAPABILITY OF TRANSMITTING FROM EITHER A HORIZONTALLY POLARIZED ANTENNA OR A VERTICALLY POLARIZED ANTENNA. IN EITHER CASE, BOTH THE TRANSMITTED POLARIZATION ("LIKE" POLARIZED) AND THE CROSS POLARIZATION ("CROSS" POLARIZED) SIGNAL RETURNS ARE RECEIVED SIMULTANEOUSLY AND PRESENTED AS SIDE BY SIDE IMAGES.

HH HORIZONTAL TRANSMIT, HORIZONTAL RECEIVE (LIKE)
HV HORIZONTAL TRANSMIT, VERTICAL RECEIVE (CROSS)
VV VERTICAL TRANSMIT, VERTICAL RECEIVE (LIKE)
VH VERTICAL TRANSMIT, HORIZONTAL RECEIVE (CROSS)

Fig. 4. SLR polarization terminology.

The striking difference between visual photography and radar imagery is the ability of the latter to penetrate more easily vegetation, camouflage, and natural color blendings of the target and reveal more clearly the topography of the bare ground beneath. It has even been proposed by certain workers in this field that ground penetration (especially dry) has been accomplished up to 3 meters at long wavelengths (1 meter). Of course, shallow water depths cannot be determined; neither salt nor silt content. Recently revealed tidal flats, or plant growth such as kelp which just break the surface have been displayed. Underwater growths or other shallow water obstructions might be detected as they affect water current or waves (breakers or surf).

COLOR ENHANCEMENT

Another special technique involving Radar Mapping Surveillance has been investigated and requires further study at the time of this report. The areas of computer data processing and image enhancement by color TV (University of Kansas), and radar design improvements: better resolution, distortion reduction, multiple wavelengths, and signature research (Westinghouse) all point to advanced possibilities in the use of SLR in the Hysurch system.

MAPPING SERVICES

Commercial mapping services are presently available which could be used for the purposes mentioned in the beginning of this report. The following is a list of specifications for the service.

1. Company: Westinghouse Electric Corp.,Baltimore,Maryland
2. Aircraft: Grumman Gulfstream
3. Radar
   (a) Model AN/APQ-97
   (b) Dual polarization capability
   (c) K band carrier frequency
   (d) Pulse Width: 10 nanoseconds
   (e) Pulse Repetition Frequency: 1,000 pps
   (f) Weight: 2,000 lbs.

4. Antenna (a) Two 13-foot assemblies, one above the other.
(b) Total weight: 900 lbs.
(c) Set up for one-sided imagery
(d) Resolution: 50 ft.

5. Operating Altitudes: 20,000 ft.
6. Width of Swath: 13-15 miles
7. Recorded image: Two 4-inch traces for like and cross-polarized returns.
8. Analysis time: 2 hrs after flight
9. Cost: Mapping Service $10.00/square mile + $4.00/linear mile, one-way. Prices subject to change.

Radar Equipment Purchase: $1,000,000 including necessary maintenance spares.

SECTION 2

Sensors Investigation: Laser Fathometer

GENERAL

As part of the Hysurch requirement, the Laser Fathometer has been investigated for feasibility and applicability towards measuring shallow water depths. The technical specification which has evolved from this study has been submitted to the US Naval Oceanographic Office and is entitled, "Performance Requirements for Pulsed Light Airborne Depth Sounder". It was evident early in the investigation that should it be necessary to operate in unfriendly waters, operation from an aircraft would be faster and less vulnerable than a sounding boat. Furthermore, the state of the art in power and detection capabilities limits laser operation in deep and turbid waters; thus, a shallow water requirement of 30 ft or 3 attenuation lengths* should be an initial goal. The altitude of the aircraft would serve to further advantage in the telemetry of information to the mothership.

ATTENUATION COEFFICIENT

Whereas the efficient use of a light beam, coherent or incoherent, requires knowledge of the transmitting medium, a major portion of the effort has been expended in this area.

For a medium such as ocean water, which covers over 70% of the earth's surface, we find its characteristics as varied as the locale. If, however, we can extract some basic or general characteristics first, the deviations from these can then be distinguished. One parameter basic to the study of electromagnetic radiation through a medium is that of attenuation. Consider Fig. 5 which represents a volume of transmitting medium, "d" units long. Let

I_o = initial light intensity at inlet to medium

I = light intensity emitted at outlet of medium

I_s = light intensity of scattered light due to medium

*Defined later in text.

Then, by experiment we can determine that

$$I = I_o e^{-\alpha d}$$

where α = attenuation coefficient in ln/meter

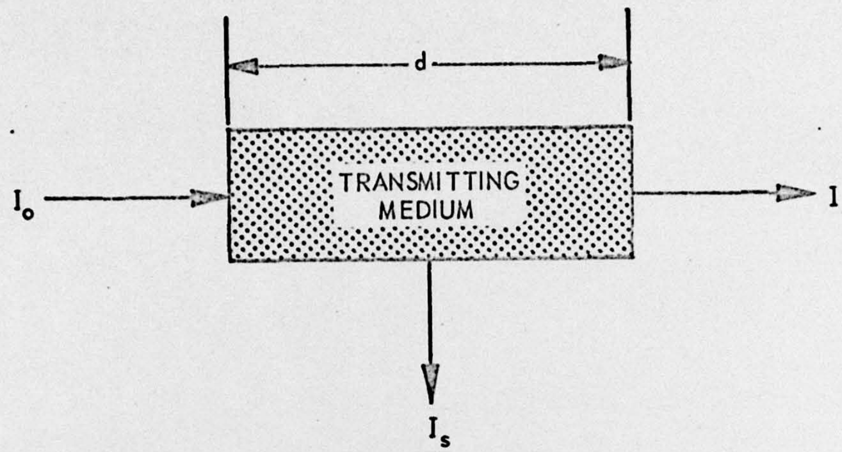


Fig. 5. Radiation through a medium.

The attenuation coefficient, α, then can be calculated through the ratio of intensities I/I_o at some standard units of length, say in meters.

$$\text{If now, } I/I_o = \frac{1}{e} = e^{-\alpha d} \tag{2}$$

$$\text{then} \quad +\alpha d = 1 \tag{3}$$

$$\text{and} \quad d = + \frac{1}{\alpha} \tag{4}$$

The expression $\frac{1}{\alpha}$ is useful in oceanographic practice because its units are expressed in distance and is defined as "attenuation length". Thus, if the light intensity is reduced by one natural logarithm "e" in a distance of 3 meters, the water is

said to be "3 meter water" or have an attenuation length of 3 meters. Conversely, the attenuation coefficient $= \frac{1}{d} = \frac{1}{3}$. It follows that the light intensity is reduced by $\frac{1}{e^2}$ in two attenuation lengths, etc.

In passing a light beam through water, we find that not all wavelengths are transmitted equally. The commonly used basis of comparison is the graph of Fig. 6 which displays the attenuation length of distilled water versus wavelength. It is evident from Fig. 6 that a "window" exists in the blue-green region of the spectrum at 4800Å. Before we investigate the reason for this phenomenon, let us experiment with a more realistic sample of ocean water. If we do, the results show a shift in the window towards the green and yellow frequencies of the visible spectrum but with a reduction in attenuation length of 50% or more*. Thus, in the more turbid coastal and estuarine waters, green and yellow light can penetrate to greater depths than blue light, although not as deep as blue light in distilled water.

SCATTERING AND ABSORPTION.

The phenomena associated with light attenuation are attributed to two main mechanisms: that of (1) scattering and (2) absorption. Thus we can say that $\alpha = s + a$

where s = scattering coefficient

and a = absorption coefficient

Scattering is a process by which the direction of light is changed without any other alteration. This process is random in nature, however, and accounts for the spreading or blurring

*The search for a "standard bucket of water" to compare laser performance goes on. It is evident that a standard for comparison is desirable, but its relation to reality must be maintained. Perhaps a given volume of distilled water with measured quantities of plankton-type suspensions with graduations in particle size would be useful.

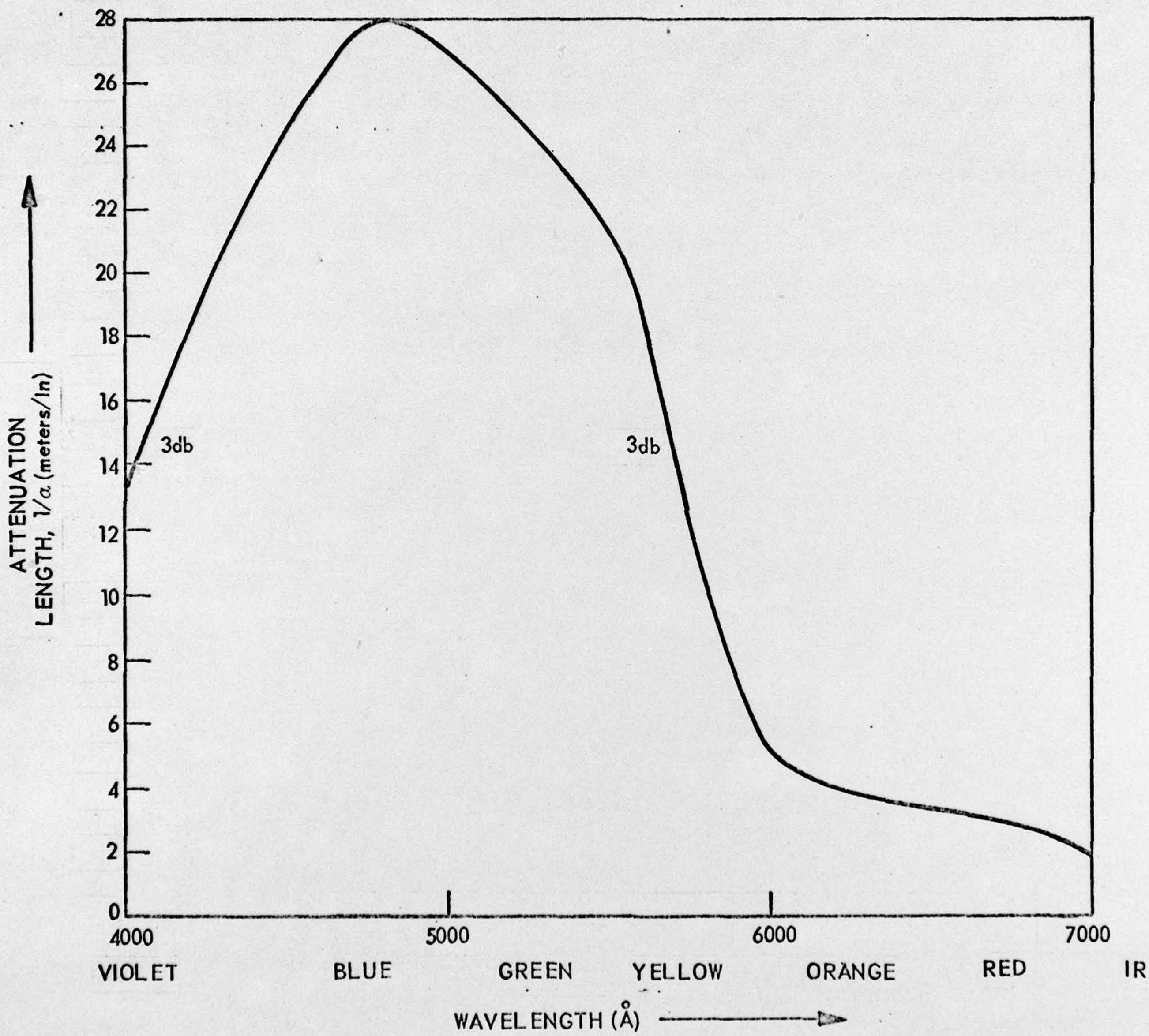


Fig. 6. Attenuation length of water (distilled) at various wavelengths.

and subsequent reduction in intensity of the original beam. In a darkened room a scattered component of intensity (I_s in Fig. 5) which is perpendicular to the main axis of the beam can be detected by observing the transmitting medium from the side. If the particles in the medium are small compared to the wavelength of the beam, "Rayleigh scattering" takes place. This is an interesting mechanism based upon what happens to the light waves as they encounter molecules in their path. Longer wavelengths "ride over" the molecules of small size, whereas the shorter wavelengths are effectively blocked or reflected. Rayleigh quantified these results to produce the graph of Fig. 7 and showed that for particles smaller than the wavelength of the light beam, the intensity is proportional to $1/\lambda 4$. For example, red light (λ = 7200Å) has a wavelength 1.8 times as great as violet light (λ = 4000Å). Thus, the intensity reduction of red light versus violet light is $\frac{1}{(1.8)^4} \simeq 10$ for particles much smaller than either wavelength (see Fig. 7). For the molecules in clear atmosphere and distilled water, the molecular diameter ($\simeq$ 10Å) is well below the wavelengths of the visible spectrum and thus Rayleigh scattering is present*. If, however,

*It is the Rayleigh scatter phenomenon which is responsible for the blueness of the sky on a clear day. The molecular scattering of white sunlight at angles from the direct rays makes the sky appear bright as well as blue. Otherwise, the sky would appear black. Air molecules are randomly spaced, and light scattered in any direction but the forward direction has random phases which are not cancelled out. Thus, the intensity of scatter is proportional to the average distance between air molecules. In our atmosphere, the gases are thick enough to produce the blue of the sky. By the same reasoning, the direct rays of the setting sun appear red as the scattering removes the blue portion of the spectrum.

Contrary to expectation, there is less Rayleigh scatter in pure water than in air. Despite the large concentration of molecules in a liquid, the distance between them is somewhat fixed. Since scatter is a random process, the random phases of scattered light other than in the forward direction are quickly destroyed. If, however, the water is not pure and contains minute suspended particles (which even clear ocean water has) the scattering effect produces an apparent blueness.

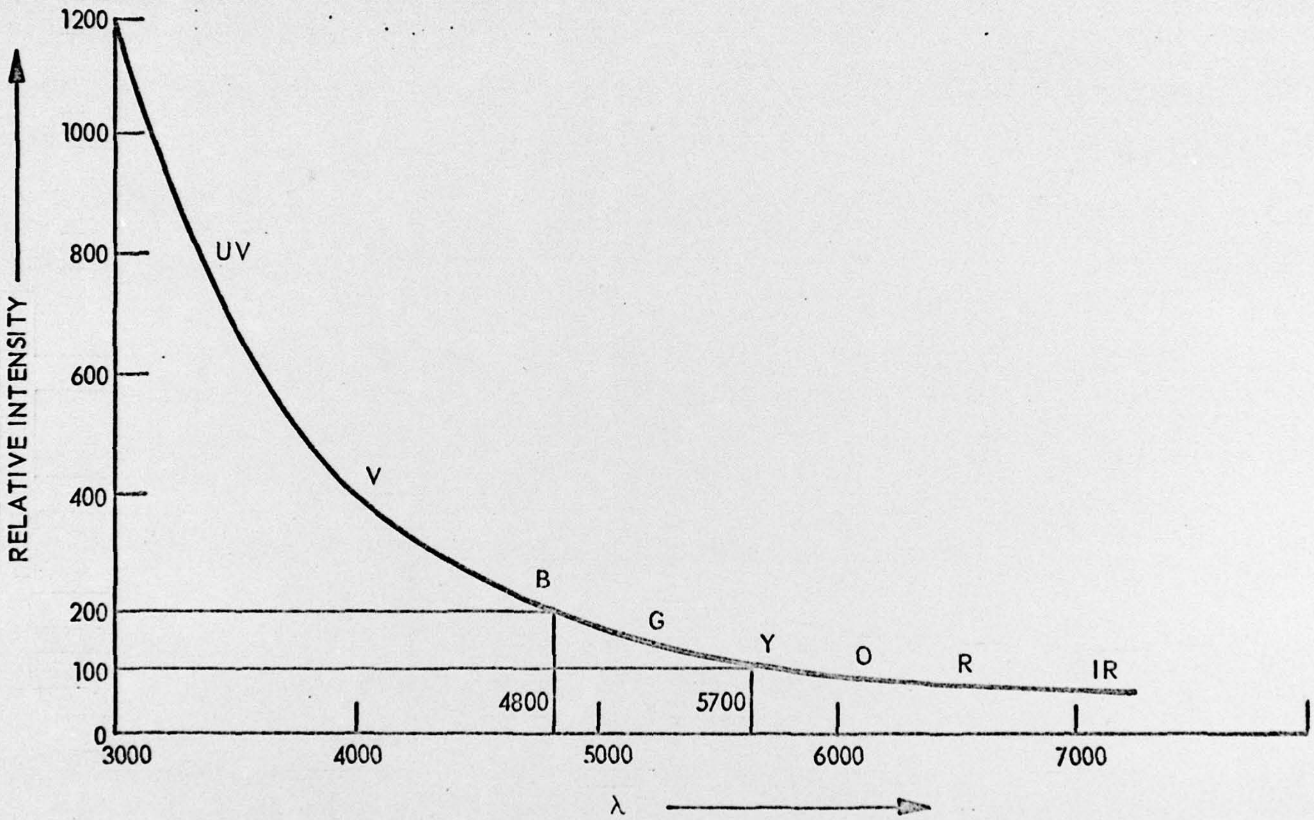


Fig. 7. Intensity of scattering vs. wavelength according to Rayleigh's law.

particles of larger diameter are now added to the medium, so that their size equals or exceeds the wavelengths involved, then the light is merely reflected and scattered independent of wavelength. In fact, scattering of light in the sea is predominantly due to transparent biological organisms (plankton) and particles large compared to the wavelength of light.

Absorption, on the other hand, is the actual disappearance of light by the conversion of light energy to other forms such as heat and chemical energy. Transformation of light into chemical energy by the process of photosynthesis is necessary for the ecology of the sea; transformation of light into thermal energy, however, is the major contributor to absorption in the sea. To give an example of the comparison of scattering and absorption effects in the ocean, in clear "blue" water with a window @ 4800Å,

$$\alpha = 0.05$$
$$s = 0.03$$
$$a = 0.02$$

In all other spectral regions, however, absorption predominates. As the water becomes turbid, on the other hand, the total attenuation, α, increases and the frequency "window" shifts towards the yellow end of the spectrum.

Equipment Considerations

With the above as background for the use of laser beams as depth finders, we may now examine the possibilities. Suppose a laser beam is mounted in an aircraft and aimed at the nadir*, and pulsed once (see Fig. 8). The burst of energy will travel through the atmosphere, encounter the air-water interface with a large energy of reflection and travel through the water to the bottom. In its latter mode, light energy will be continually backscattered (small) as well as forwardscattered (large). If the bottom is re-

*Assume the laser carrier frequency is in the blue-green portion of the spectrum for maximum penetration.

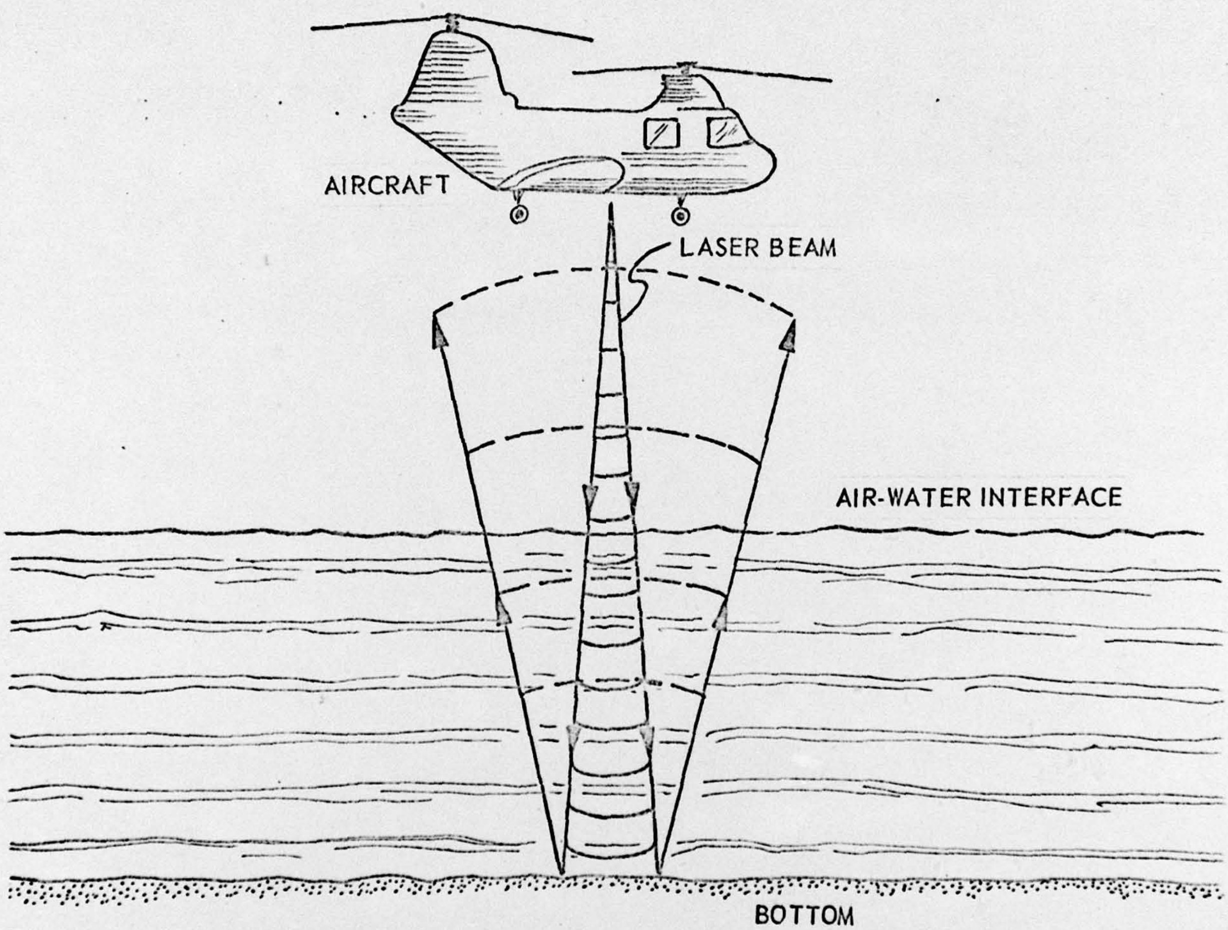


Fig. 8. Typical diagram of scattering effect.

flective, the energy will be reflected much the same way as a radar pulse. If the bottom is dark and absorptive, the energy is not returned. The profile of the returned light energy is expected to look ideally like that of Fig. 9.

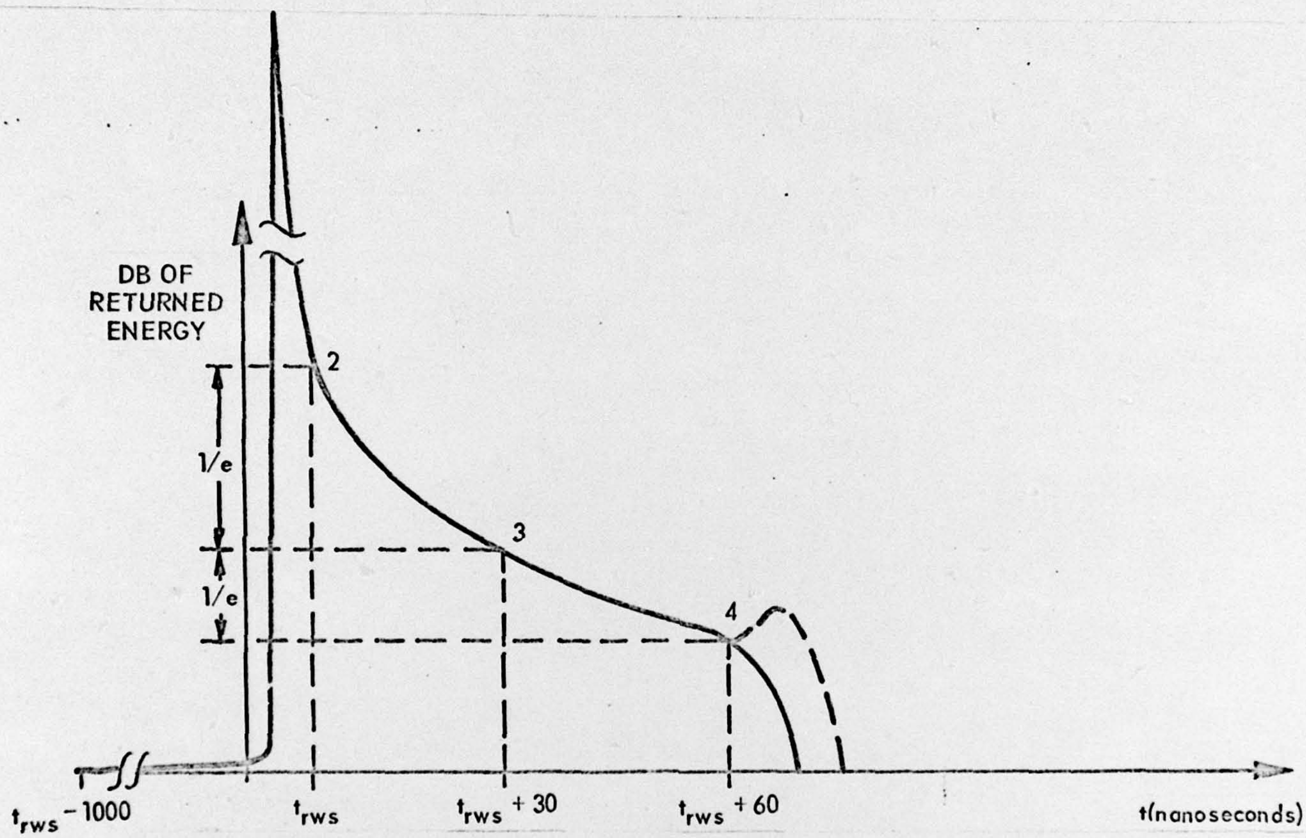


Fig. 9. Profile of returned laser pulse.

Let the pulse width be 1 nanosecond (nsec) long, and approximate the speed of propagation as 1 ft/nsec. If the altitude of the aircraft were 500 ft., then at t_{rws} (where t_{rws} = reference water surface) a large energy of reflection would be returned to the detection receiver; (between points 1 and 2 Fig. 9). It would be desirable at this point to gate out the receiver to prevent

saturation and oscillation effects from deteriorating the receiver characteristics. The timing of this gate is variable with altitude and would have to be closed-loop controlled by another laser beam or other device acting as an altimeter. Assuming the proper conditions for entry of the beam into the water; viz., no solid obstacles, plant life, or heavy froth, the returned energy of backscatter would look exponential, (points 2 to 3 and 3 to 4, Fig. 9). If this exponential could be properly recovered and calibrated, the attenuation coefficient, α , could be extracted. The curve takes the form of $y = e^{-x}$. With the proper circuitry, say logarithmic diodes, the curve from points 2 to 4 might be biased out and amplified for maximum sensitivity.

The timing of the backscatter between points 2 and 4, from (t_{rws}) to $(t_{rws}+60)$ would be a measure of the water depth. With accuracy specifications of $\pm$ 1.5 feet, it is necessary to choose wisely point 2 (where the receiver is unblocked) and point 4 (where the bottom either reflects or absorbs). Since 1.5 feet in range is only nanoseconds of time, much experience and clever circuit design will be needed.

Bibliography

1. Radar mapping surveillance set AN/APQ-97 (Confidential)

2. "Side Look Radar" Brochure, by Westinghouse Electric Corp., Sept. 1967.

3. Proceedings of the Third Space Congress: "Use of Orbital Radars for GeoScience Investigations", by J.W. Rouse, Jr., W.P. Waite, and R.L. Walters, University of Kansas, March 1966, Cocoa Beach, Fla.

4. "Selected Bibliography of the Terrain Sciences", by Robert F. Holmes and Joseph J. Footen, Autometrics Division of Raytheon Company.

5. Aviation Week and Space Technology Magazine, May 8, 1967, Advertisement, pages 57-64.

6. "Light in the Sea", by Seibert Q. Duntley, J. Opt. Soc. Am., Vol. 53, pp. 214-233, February 1963.

7. U.S. Naval Oceanographic Office, "Airborne Laser System Measures Ocean Surface Environment", Laser Focus, Vol. 3, No. 7, pp. 17-20, April 1967.

8. "Fundamentals of Optics", F.A. Jenkins and H.E. White, McGraw Hill Co., Chapter 22, Third Edition, 1957.

9. "Oceanography and Underwater Sound for Naval Applications", Special Publication, SP-84, October 1965, by the U.S. Naval Oceanographic Office.

10. "Physical Oceanography", by Albert Decant, Vol.1, Pergaman Press, The MacMillan Co., N.Y., 1961.